Accelerated Artificial Corrosion Monitoring of Reinforced Concrete Slabs Using the Half-Cell Potential Method

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Overview

- Motivation and Objective
- Experimental Approach
  - Accelerated corrosion test
  - Data collection
- Results
  - Data modeling
- Conclusions
- Acknowledgements
- References
Motivation and Objective

• Why Monitor Corrosion?
  – Corrosion affects the service life of concrete structures
  – Corrosion is inevitable
  – Many structures were built with unprotected rebar

• Half-Cell Potential
  – Standardized test
  – Proven Reliability

(Source: www.fhwa.dot.gov)
Motivation and Objective

Case: MA Route 6A over Scorton Creek
Sandwich, MA

Cracking to Interior Beam at Midspan
Spalling of South Exterior Beam
Motivation and Objective

Goals

- Determine how the spatial distribution of half-cell potential (HCP) measurements on Reinforced Concrete (RC) slabs change in time
- Perform a visual inspection to validate the results
- Develop parameters for the distribution of HCP in the time domain
- Compare the HCP data at varying concrete covers to an non-ponded RC slab in the same environment
Experimental Approach
Experimental Approach

Concrete Laboratory, CEE, UMass Lowell
Experimental Approach

- Adapted version of the Modified Southern Exposure Test [2]
- Controlled environment
  - Relative humidity kept to 50%
  - Temperature 73°F when ponding
  - Temperature 100°F when drying
- Slabs ponded in weekly cycles for 52 weeks
  - 4 days of ponding
  - 3 days of drying
- Slabs covered with a tarp to keep conditions constant
Experimental Approach

Specifications

- Elcometer 331² Model H
- Ag/AgCl reference electrode
- Readings corrected to Cu/CuSO₄ values
- Test specification
  – ASTM C678 - 09
- Procedure similar to the Modified Southern Exposure Test

Elcometer 331² ® Model H & HM Half Cell Meter
Source: www.elcometer.com
Experimental Approach

Factors Affecting HCP Measurement

- **Concrete Cover**
  - Influences the rate of corrosion

- **Location of Measurement**
  - Least resistivity when measurements are taken directly over the bars

- **Water Content**
  - Affects the resistivity of the concrete

- **Atmospheric Conditions**
  - Affects the water content of the slab
Results - Slab 1

Concrete Laboratory, CEE, UMass Lowell (Week 52)
Results – Slab 1

S1-1

HCP = -530 mV

Concrete Laboratory, CEE, UMass Lowell
(Week 52)
Results – Slab 1

S1-2

HCP = -501 mV

Concrete Laboratory, CEE, UMass Lowell
(Week 52)

S1-3

HCP = -422 mV
Contour maps were as expected for Slab 1
HCP Contour Maps

(Slab 2)

Half Cell Potentials: Slab 2

Slab 2 shows lower HCP at the front of the slab.

-Spatial location of the point of measurement is important.
HCP Contour Maps

Slab 3 shows more corrosion with areas of less concrete cover
–Variations in concrete cover affect HCP
The contour map for Slab 4 was as expected—it shows minor variations across the entire slab.
Average HCP vs. Time

Graphical Representation

![Graphical Representation of Average HCP vs. Time](image-url)
Observations

- All Slabs show an increase until Week 14
  - Residual pore water
- Slab 2 stays fairly constant after Week 28
  - About (-140 mV)
- Slab 3 shows more variability than Slab 2, but stays relatively constant after Week 24
  - About (-240 mV)
- Slab 4 is more noisy than the minimum values
## Average HCP vs. Time

### Model Parameters

The model equation is given by:

$$HCP(t) = P_1 t^4 + P_2 t^3 + P_3 t^2 + P_4 t + P_5$$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Slab 1</th>
<th>Slab 2</th>
<th>Slab 3</th>
<th>Slab 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>3.399e-4</td>
<td>-3.614e-5</td>
<td>-4.226e-5</td>
<td>-3.736e-4</td>
</tr>
<tr>
<td>$P_3$</td>
<td>0.6127</td>
<td>-0.2572</td>
<td>-0.8518</td>
<td>-1.725</td>
</tr>
<tr>
<td>$P_4$</td>
<td>2.375</td>
<td>7.219</td>
<td>24.43</td>
<td>25.23</td>
</tr>
<tr>
<td>$P_5$</td>
<td>-280.2</td>
<td>-247.3</td>
<td>-485.4</td>
<td>-263</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.98</td>
<td>0.91</td>
<td>0.66</td>
<td>0.56</td>
</tr>
</tbody>
</table>
Minimum HCP vs. Time

Graphical Representation

Minimum HCP Measurements (as of week 52)

- Minimum HCP (mV)
- Time (weeks)

Legend:
- Slab 1, 1.5"
- Slab 2, 2"
- Slab 3, 2"
- Slab 4, 1.5"
Observations

- Slab 1 shows an expected, decreasing trend
- Slab 2 stays fairly constant throughout the entire experiment (-180 mV)
- Slab 3 dips sharply at the start, but remains constant afterward (-550 mV)
  - Possible excess mix water trapped in slab
- Slab 4 stays constant throughout the first 30 weeks, but rises afterwards (-120 mV)
  - Possible indicator of background noise
# Minimum HCP vs. Time

## Model Parameters

\[ HCP(t) = P_1 t^4 + P_2 t^3 + P_3 t^2 + P_4 t + P_5 \]

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</tr>
</thead>
<tbody>
<tr>
<td>( P_1 )</td>
<td>-3.722e-4</td>
<td>1.575e-5</td>
<td>1.860e-5</td>
<td>-5.037e-4</td>
</tr>
<tr>
<td>( P_2 )</td>
<td>6.16e-2</td>
<td>9.032e-4</td>
<td>-2.116e-3</td>
<td>5.574e-2</td>
</tr>
<tr>
<td>( P_3 )</td>
<td>-3.21</td>
<td>-0.1928</td>
<td>0.1145</td>
<td>-1.988</td>
</tr>
<tr>
<td>( P_4 )</td>
<td>49.05</td>
<td>6.771</td>
<td>-4.405</td>
<td>26.21</td>
</tr>
<tr>
<td>( P_5 )</td>
<td>-377.8</td>
<td>-234.4</td>
<td>-451.9</td>
<td>-261.5</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.97</td>
<td>0.46</td>
<td>0.31</td>
<td>0.51</td>
</tr>
</tbody>
</table>
Effect of Concrete Cover

1.5” Concrete Cover

Slab 1 (Week 52)  Slab 4 (Week 52)

47.1% Decrease in Average HCP  53.2% Increase in Average HCP
Effect of Concrete Cover

2” Concrete Cover

Slab 2 (Week 52)

Slab 4 (Week 52)

41.1% Increase in Average HCP

50.2% Increase in Average HCP
Conclusions

- Concrete cover is the most important factor determining the rate of corrosion
- Visual inspection validates the experimental results
  - Corrosion observed at the points of lowest HCP
- Data collected on Slab 4 can be used to determine the level of noise in HCP measurements
  - Further analysis required to denoise the data
Acknowledgements

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References


Thank You for your attention

Questions?